GaN-based Robust Micro Pressure and Temperature Sensors for Extreme Planetary Environments

K. Son[1], B. Yang[1], Y. Liu[2], P. P. Ruden[2], N. Biyikli[3], X. Ni[3], J. Xie[3] H. Morkoç[3], R. E. Young[4], and A. Colaprete[4]
[1]Jet Propulsion Laboratory, Pasadena, CA 91109, kson@jpl.nasa.gov
[2]Dept. of Electrical & Computer Engineering, University of Minnesota, Minneapolis, MN
[3]Dept. of Electrical Engineering, Virginia Commonwealth University, Richmond, VA
[4]NASA Ames Research Center, Moffett Field, CA 94035

We are developing a robust AlGaN/GaN-based microsensor that is capable of simultaneous temperature and pressure measurements in harsh planetary atmosphere. The AlGaN/GaN sensor has small volume (<1cm^3), low mass (<5g), and low power requirement (<10 mW) and can operate at extreme temperatures (-250 to 600 °C) and pressures (0 bar to 10 Kbar) and in strong radiation (> 5 Mrad) environments. Measuring the thermal structure of a planet's atmosphere under extreme conditions, the AlGaN/GaN microsensor can be a key element for future entry probes for *in situ* planetary atmospheric investigation.

The III-nitride compounds based on the AlGaN alloy have large band gaps (3.4-6.1 eV) and strong atomic bonds. Consequently, these semiconductors exhibit favorable mechanical, thermal, and chemical stabilities with minimal problems arising from the unwanted optical or thermal generation of charge carriers. Therefore they are ideal materials for constructing sensors for applications in extreme and harsh environments. One of the unique advantages of GaN-based devices is that AlGaN/GaN heterostructures develop sheet charges at the hetero-interfaces due to the piezoelectric and spontaneous polarizations between AlGaN and GaN layers. Applied stress modulates this interfacial polarization charge due to differences in the piezoelectric coefficients of AlGaN and GaN, and therefore the barrier height (that controls transport across the interface) is modulated. We utilize this stress-induced modulation of the barrier height for pressure sensing. Mobility of the electrons in the polarization sheet changes with temperature due to scattering. We use this temperature-induced mobility change for temperature measurements.

Among the various AlGaN/GaN heterostructure devices, we have investigated n-GaN/$Al_xGa_{1-x}N$/n-GaN (n-I-n) vertical transport devices and high electron mobility transistors (HEMTs) for pressure and temperature sensing applications. Theoretical modeling of n-I-n sensors performed with various compositions (x = 0.1, 0.15, & 0.2) of $Al_xGa_{1-x}N$ suggests that electrical currents will decrease with increased pressure and this effect becomes more significant with higher AlN compositions in the $Al_xGa_{1-x}N$ layer. The effects of hydrostatic pressure on the electrical properties of n-GaN/$Al_{0.15}Ga_{0.85}N$/n-GaN structures measured over the range of 0-6 kbar show that the current decreases linearly and reversibly with increasing pressure.

The current-voltage characteristics of various $Al_{0.3}Ga_{0.7}N$/n-GaN HEMT sensors have been measured under hydrostatic pressure of 0-2 kbar. The results show that the drain current increases with pressure and the maximum relative increase occurs when the gate bias is near threshold and drain bias is slightly larger than saturation bias. The increase of the drain current is associated with a pressure-induced shift of the threshold voltage by -8.0mV/kbar. The linearity and reversibility in pressure response observed with both n-I-n and HEMT sensors suggest that they are promising for pressure sensor applications in extreme environments. Temperature effects on electrical properties of the GaN-based sensors have also been measured, and detailed analysis on the results is in progress.